Surface-Soil Properties in Response to Silage Cropping Intensity under No Tillage on a Typic Kanhapludult

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ABSTRACT

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues returned to soil will likely alter the success of a particular conservation tillage system within a farm operation. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments. We investigated the impact of three cropping systems (a gradient in residue returned to soil) on soil bulk density, aggregation, organic C and N, and microbial biomass and activity in a Piedmont soil in North Carolina USA. There is an inverse relationship between silage intensity and residue returned to soil. With time, soil bulk density became lower and soil organic C, total soil N, and size and stability of mean-weight diameter of water-stable aggregates became higher with reduced silage cropping intensity as a result of greater crop residue returned to soil. Soil microbial biomass C and its potential activity were significantly greater in surface depths with reduced silage cropping intensity. These results suggest that greater quantities of crop residue returned to soil have a multitude of positive effects on soil properties, even in continuous no-tillage crop production systems. These results can help to determine an optimum balance between short-term economic returns and longer term investments in improved soil quality for more sustainable production.

Keywords: Aggregation; Bulk density; Microbial biomass; Organic carbon; Soil quality; Total nitrogen

INTRODUCTION

Soil quality is a concept based on the premise that management can deteriorate, stabilize, or improve soil ecosystem functions. Soil provides a medium for plant growth, regulates and partitions water flow in the environment, and buffers the fluxes of natural and xenobiotic compounds through decomposition and fixation processes (Larson and Pierce, 1991). The organic components of soil are important in providing energy, substrates, and the biological diversity necessary to sustain many soil functions.

Conservation tillage systems are now widely adopted by many producers, because they
- reduce fuel, time, and labor needed to make multiple tillage operations,
- reduce machinery wear
- allow for more timely planting of crops even under wetter soil conditions
- improve soil and water quality
- reduce runoff and make more effective use of precipitation
- improve wildlife habitat
- meet Farm Bill requirements

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a farm operation. Crop residues left at the soil surface as a surface mulch are important for feeding the soil biology, suppressing weed seed germination, and suppressing wide fluctuations in temperature and moisture that can hinder plant development. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments.

Dairy producers in North Carolina USA rely on maize (*Zea mays* L.) and barley (*Hordeum vulgare* L.) silage as sources of high quality feedstuffs in their rations. High-intensity silage cropping is typically practiced to maximize the amount of feedstuffs produced per unit of land area. High-intensity silage cropping, however, leaves little residue at the soil surface, offering little buffer against equipment traffic. The lack of residue returned to the soil under high-intensity silage cropping brings into question issues of long-term compaction, water-use efficiency, nutrient cycling, and soil erosion even when conservation tillage is used.

We investigated the impact of alternative, reduced-silage-cropping-intensity systems that returned more crop residues to the soil than the traditional maize-barley silage cropping system on surface-soil properties. We consider the soil surface a critical component of agroecosystems, because it is the vital interface that initially determines the fate of fertilizers, pesticides, water, and gases into and out of the soil profile.

METHODS

The site is located in Iredell County in the Southern Piedmont Major Land Resource Area of North Carolina USA (36 EN, 81 EW). Soils are mostly Fairview sandy clay loam (fine, kaolinitic, mesic Typic Kanhapludult) in Replication 1 and Braddock loam (fine, mixed, semiactive, mesic Typic Kanhapludult) in Replication 2. These soils are classified as well drained with moderate permeability. Mean annual precipitation is 1220 mm and mean annual temperature is 14.4 EC.

Three cropping systems replicated twice were evaluated in - 300-m-long strips that were 12-20-m wide each. Plots were managed by the owner with his field equipment. Replication 1 was established in 1998 and Replication 2 was established in 2000. All plots were managed with no tillage for several years prior to, as well as during experimentation. Previous management of the field with no tillage was without high residue input. Prior to no tillage, this field was managed with a 2- to 4-year rotational strip cropping system of perennial forage with maize silage. Fertilizer as liquid dairy manure was applied in spring at a rate of 18,000 to 22,000 L · ha^{-1} · yr^{-1}, which was equivalent to 45-15-93-8 kg N-P-K-S · ha^{-1}.

The three cropping systems were designed as a gradient in silage intensity and inversely related to the amount of crop residues returned to the soil. The traditional cropping system (high silage intensity) was maize silage planted in May and harvested in September followed by barley silage

planted in November and harvested in April. This was a one-year rotation and had the least above-ground residue returned to the soil. A medium silage intensity system was maize silage planted in May and harvested in September followed by a winter cover crop [rye (*Secale cereale* L.) alone or rye plus crimson clover (*Trifolium incarnatum* L.)] killed by a herbicide in April. This was a one-year rotation and had a moderate level of crop residue returned. A low silage intensity system was maize silage planted in May and harvested in September followed by barley planted in November and harvested for grain in June. Barley straw was left in the field and a summer cover crop [sudangrass (*Sorghum sudanense* Hitchc.) or sunnhemp (*Crotalaria juncea* L.)] planted in June and killed by frost in October. The summer cover crop was left in the field and followed by planting of rye as a winter cover crop in November, which was killed by a herbicide in April and left in the field. This was a two-year rotation and had the highest level of crop residue returned. Expressed as silage cropping intensity, treatments had 1 (low silage intensity), 2 (medium silage intensity), and 4 (high silage intensity) silage crops harvested during a 2-year period.

Surface residue and soil were sampled in December 2000, February 2002, and November 2002. In December 2000, plots were sampled in duplicate by splitting the plot in half to assess within-plot variability. For each sample collected, eight sites located - 20 m apart were composited. Surface residue was collected from 20- x 20-cm areas by first removing green plant material above - 4-cm height and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core (4-cm diam) was sectioned into depths of 0-3, 3-6, 6-12, and 12-20 cm. Soil was dried at 55 EC for 3 days, initially passed through a sieve with openings of 4.75 mm to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device.

Dry aggregate distribution was determined by placing a 100-g subsample of soil on top of a nest of sieves (20-cm diam with openings of 1.0, 0.25, and 0.05 mm), shaking for 1 min at level 6 on a CSC Scientific Sieve Shaker (Catalogue No. 18480), and weighing soil retained on the 1.0-, 0.25-, and 0.05-mm screens and that passing the 0.05-mm screen. Water-stable aggregate distribution was determined from the same soil sample used for dry aggregate distribution placed on top of a nest of sieves (17.5-cm diam with openings of 1.0 and 0.25 mm), immersed directly in water, and oscillated for 10 min (20-mm stroke length, 31 cycles · min^{-1}). After removing the two sieves and placing them in an oven to dry, water containing soil passing the 0.25-mm sieve was poured over a 0.05-mm sieve, soil washed with a gentle stream of water, and the soil retained transferred into a drying bottle with a small stream of water. The <0.05-mm fraction was calculated as the difference between initial soil weight and summation of the other fractions. All fractions were oven-dried at 55 EC for 3 d. Mean-weight diameter of both dry- and water-stable aggregates was calculated by summing the products of aggregate fractions and mean diameter of aggregate classes. Stability of mean-weight diameter was calculated as water-stable mean-weight diameter divided by dry-stable mean-weight diameter.

Potential C mineralization was determined by placing two 20- to 65-g subsamples (inversely related to soil organic C concentration) in 60-mL glass jars, wetting to 50% water-filled pore space, and placing them in a 1-L canning jar along with 10 mL of 1 *M* NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 25±1 EC for up to 24 d. Alkali traps were replaced at 3 and 10 d of incubation and CO_2-C determined by titration with 1 *M* HCl in the presence of excess $BaCl_2$ to a phenolphthalein endpoint. At 10 d, one of the subsamples was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, vapors removed at 24 hr, placed into a separate canning jar along with vials of alkali and water, and incubated at 25 EC for 10 d. Soil microbial biomass C was calculated as the quantity of CO_2-C evolved following fumigation divided by an efficiency factor of 0.41.

Since the two replications in this experimental design were established two years apart, we chose to look at the temporal changes that occurred in soil properties through regression, rather than discrete sampling year effects. Sampling in December 2000 was after 3 years (Replication 1) and 1 year (Replication 2). Sampling in February 2002 was after 4 years (Replication 1) and 2 years (Replication 2). Sampling in November 2002 was after 5 years (Rep 1) and 3 years (Replication 2). Treatment means averaged across all three sampling events were evaluated for differences with a paired t-test. Differences among silage cropping intensity treatments were considered significant at P#0.1.

RESULTS

Soil bulk density was lowest at the soil surface and increased with depth under all three management systems (Fig. 1). Averaged across the three sampling dates, soil bulk density at a depth of 0-3 cm was lower under the alternative cropping systems (i.e., low and medium silage intensities) compared with the traditional system of high silage intensity.

Bulk density of the surface 3 cm of soil changed with time (Fig. 2). The traditional cropping system of high silage intensity led to increasing soil bulk density with time. The average rate of increase was 0.05 Mg · m⁻³ · yr⁻¹. Surface-soil bulk density under low and medium silage intensities was highly variable from one year to the next for some reason. Trends were for minor increase with time under medium silage intensity and for minor decrease under low silage intensity.

These Ultisols were highly aggregated, irrespective of cropping system. However, there were significant changes in mean-weight diameter of water-stable aggregates with time that were affected by management (Fig. 3). Mean-weight diameter at a depth of 0-3 cm declined with time under the traditional system of high silage intensity. In contrast, mean-weight diameter tended to increase with medium silage intensity and even more so with low silage intensity.

The stability of mean-weight diameter followed a pattern similar to that of the size of mean-weight diameter of water-stable aggregates (Fig. 4). One difference, though, was that there was no change at all with time in stability of mean-weight diameter under low and medium silage intensities. The stability estimate reflects the resistance of aggregates to slaking, whereas the size estimate reflects the formation of aggregates that occurs in the field. Both estimates of aggregate size and stability were sensitive to the differential amount of crop residues returned to the soil surface along the silage intensity gradient.

Soil organic C averaged across all three sampling events was not significantly different among cropping systems (Fig. 5). However, there was a tendency for greater soil organic C within the surface 6 cm
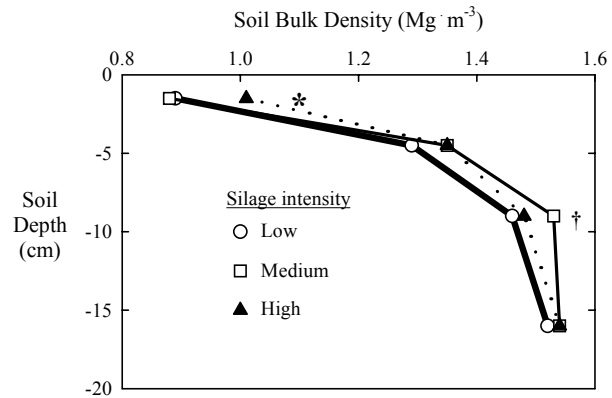

Figure 1. Soil bulk density averaged across three sampling dates as affected by depth and cropping system. * and † indicate significance between means at P#0.1 and P#0.05, respectively.
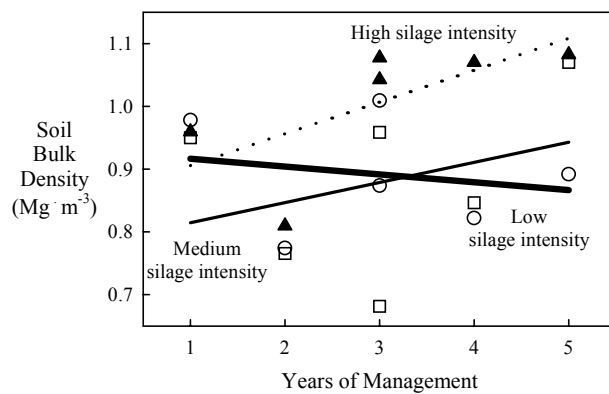

Figure 2. Temporal changes in soil bulk density at a depth of 0-3 cm as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and • is high silage intensity.
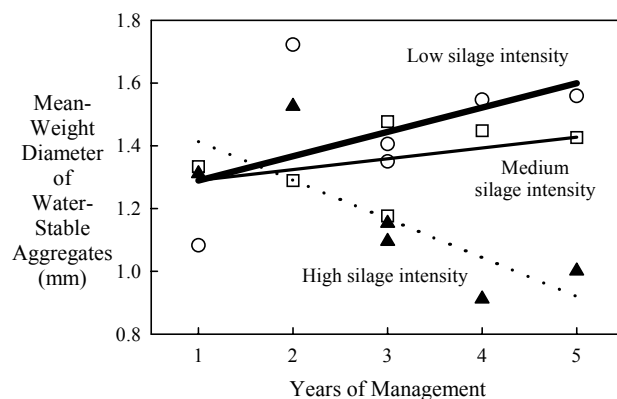

Figure 3. Temporal changes in mean-weight diameter of water-stable aggregates at a depth of 0-3 cm as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and • is high silage intensity.

under the alternative cropping systems with lower silage intensity than the traditional system with high silage intensity. Soil organic C concentrations were 3-4 times greater at the soil surface than at 12-20-cm depth, which was likely due to the long-term utilization of no tillage and liquid manure application at this location prior to and during this experiment.

From the temporal analysis, organic C of the surface 3 cm of soil was significantly affected by cropping system (Fig. 6). With the traditional system of high silage intensity, soil organic C declined with time. Under medium silage intensity, soil organic C remained stable with time. Under high silage intensity, soil organic C increased initially during the first 3 years and may have reached a plateau thereafter. Additional years of sampling will need to be conducted to verify this plateau.

Total soil N responded similarly to that of soil organic C (data not shown).

Soil microbial biomass C (and potential C mineralization) at a depth of 0-3 cm responded in a similar manner to that of soil organic C and total soil N, as a function of time relative to cropping system (Fig. 7). There was a greater tendency for a peak in soil microbial biomass to occur with low silage intensity at 3 years of management than that observed for soil organic C. However, at the end of 5 years of management, soil microbial biomass was greater under alternative cropping systems compared with high silage intensity.

DISCUSSION

This study suggests that compaction was occurring at a steady rate with high silage cropping intensity, but that compaction could be alleviated by low silage cropping intensity with high surface residue return. The slow conversion of organic matter from crop residues into soil organic C, especially at the soil surface, can lead to a large reduction in soil bulk density (Franzluebbers et al., 2001). Organic matter has a much lower specific density than mineral soil and the incorporation of organic matter with soil often leads to a more porous soil matrix as a result of soil faunal and microbial activity, which also
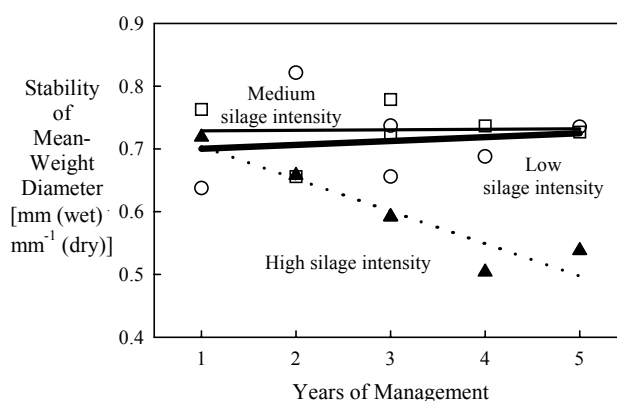

Figure 4. Temporal changes in stability of mean-weight diameter at a depth of 0-3 cm as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and • is high silage intensity.
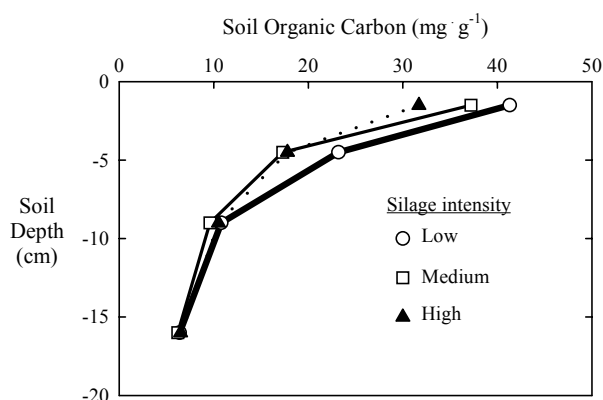

Figure 5. Soil organic carbon averaged across three sampling dates as affected by depth and cropping system. Means within a depth were not significant at P#0.1.
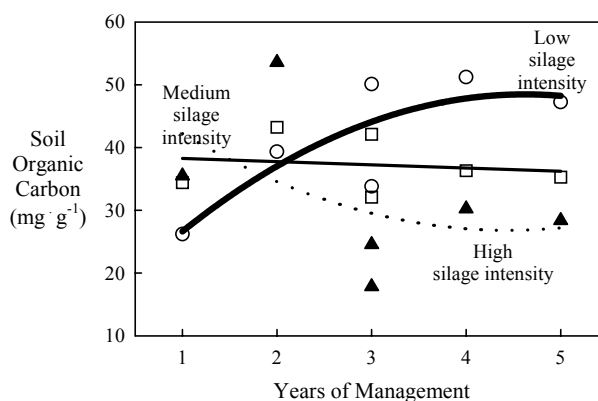

Figure 6. Temporal changes in soil organic C at a depth of 0-3 cm as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and • is high silage intensity.

fabricate water-stable aggregates.

Soil organic C and total soil N were highly stratified with depth under all management systems in this study as a result of long-term management with conservation tillage. Averaged across the three sampling events, stratification ratio (0-6 cm/12-20 cm) of soil organic C was 3.7 with high silage intensity, 4.1 with medium silage intensity, and 5.0 with low silage intensity. This stratification with depth is common in many undisturbed ecosystems (Franzluebbers, 2002). Greater quantities of crop residue were being returned to the soil with lower silage cropping intensity than with the traditional system of high silage intensity. Return of organic substrates to the soil surface are necessary to maintain high surface-soil biological activity, which fosters water and nutrient efficiency and prevents soil compaction.
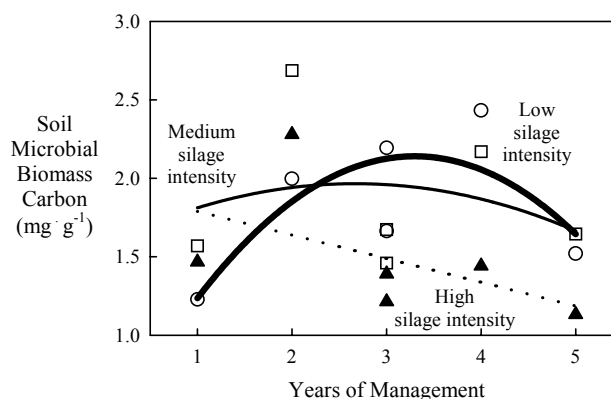

Figure 7. Temporal changes in soil microbial biomass C at a depth of 0-3 cm as affected by cropping system. ○ is low silage intensity, □ is medium silage intensity, and • is high silage intensity.

Although soil microbial biomass represented only - 5% of the soil organic C pool, it plays a major role in organic matter decomposition and nutrient cycling. Changes in soil microbial biomass may be an early indicator of long-term changes in soil organic matter (Powlson et al., 1987).

CONCLUSIONS

Sampling of surface-soil properties within the first 5 years of implementation of alternative silage crop management systems suggested that soil physical properties such as bulk density and aggregation and soil biochemical properties such as organic C, microbial biomass C, and potential C mineralization would respond positively and lead to an improvement in soil quality. Sufficient quantities of residues returned to the soil are necessary for organic matter transformations to facilitate the development of an improved soil condition. Following the conclusion of this study, we should be able to quantify the impacts of silage cropping intensity on soil and water conservation and farm economics.

ACKNOWLEDGEMENTS

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